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George et al.

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(54) **CHANNEL INTEGRITY DETECTION**

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USPC 702/72, 64–66, 182–185
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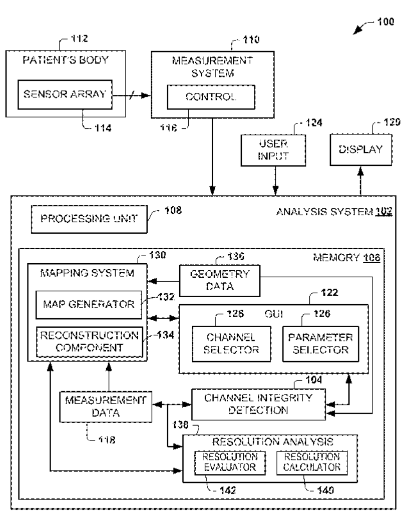
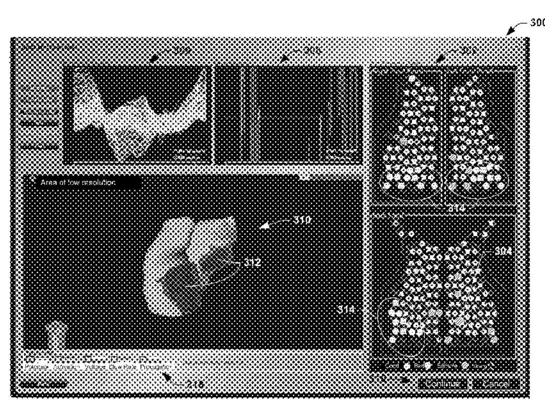
(74) *Attorney, Agent, or Firm* — Tarolli, Sundheim, Covell & Tummino LLP

(57) **ABSTRACT**

A computer-implemented method can include determining an amplitude for each of a plurality of input channels, corresponding to respective nodes. A measure of similarity can be computed between the input channel of each node and the input channel of its neighboring nodes. The method can also include comparing an amplitude for each node relative to other nodes to determine temporary bad channels. For each of the temporary bad channels, a measure of similarity can be computed between the input channel of each node and the input channel of its neighboring nodes. Channel integrity can then be identified based on the computed measures of similarity.

30 Claims, 9 Drawing Sheets





(51) **Int. Cl.**

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A61B 5/0408	(2006.01)
A61B 6/00	(2006.01)
A61B 8/08	(2006.01)
A61B 5/0476	(2006.01)
A61B 5/0488	(2006.01)
A61B 5/0496	(2006.01)
A61B 5/0428	(2006.01)

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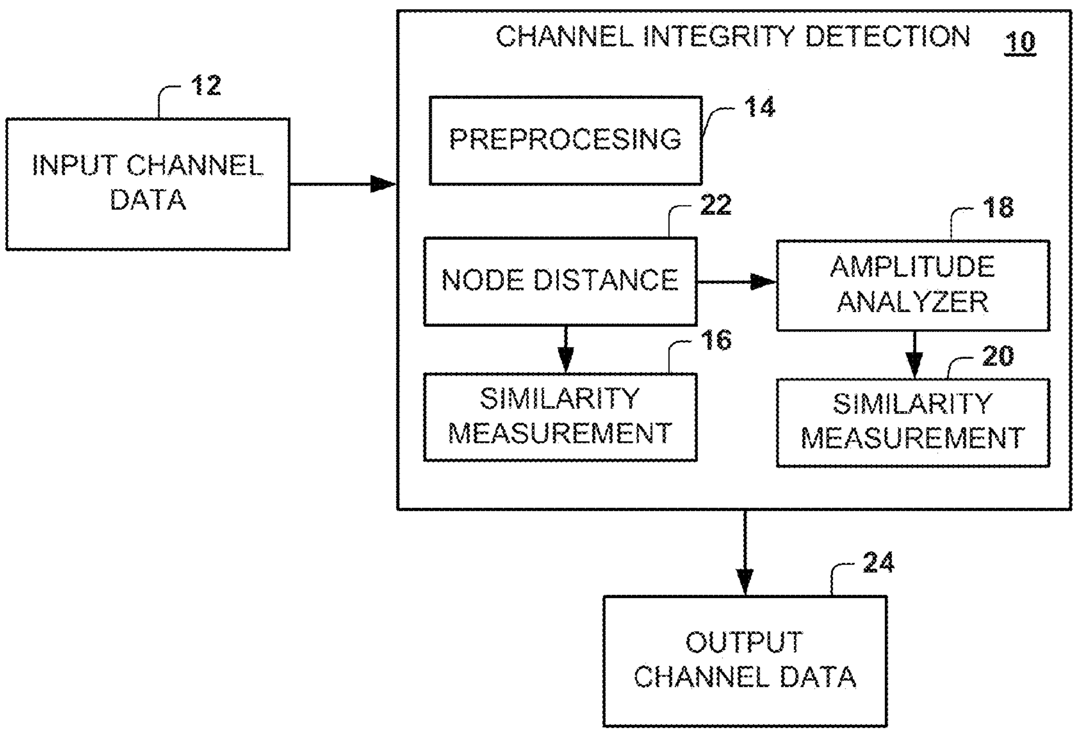

CHANNEL INTEGRITY DETECTION
10
12
INPUT CHANNEL DATA
PREPROCESING
14
22
18
NODE DISTANCE
AMPLITUDE ANALYZER
16
20
SIMILARITY MEASUREMENT
SIMILARITY MEASUREMENT
24
OUTPUT CHANNEL DATA

FIG. 1

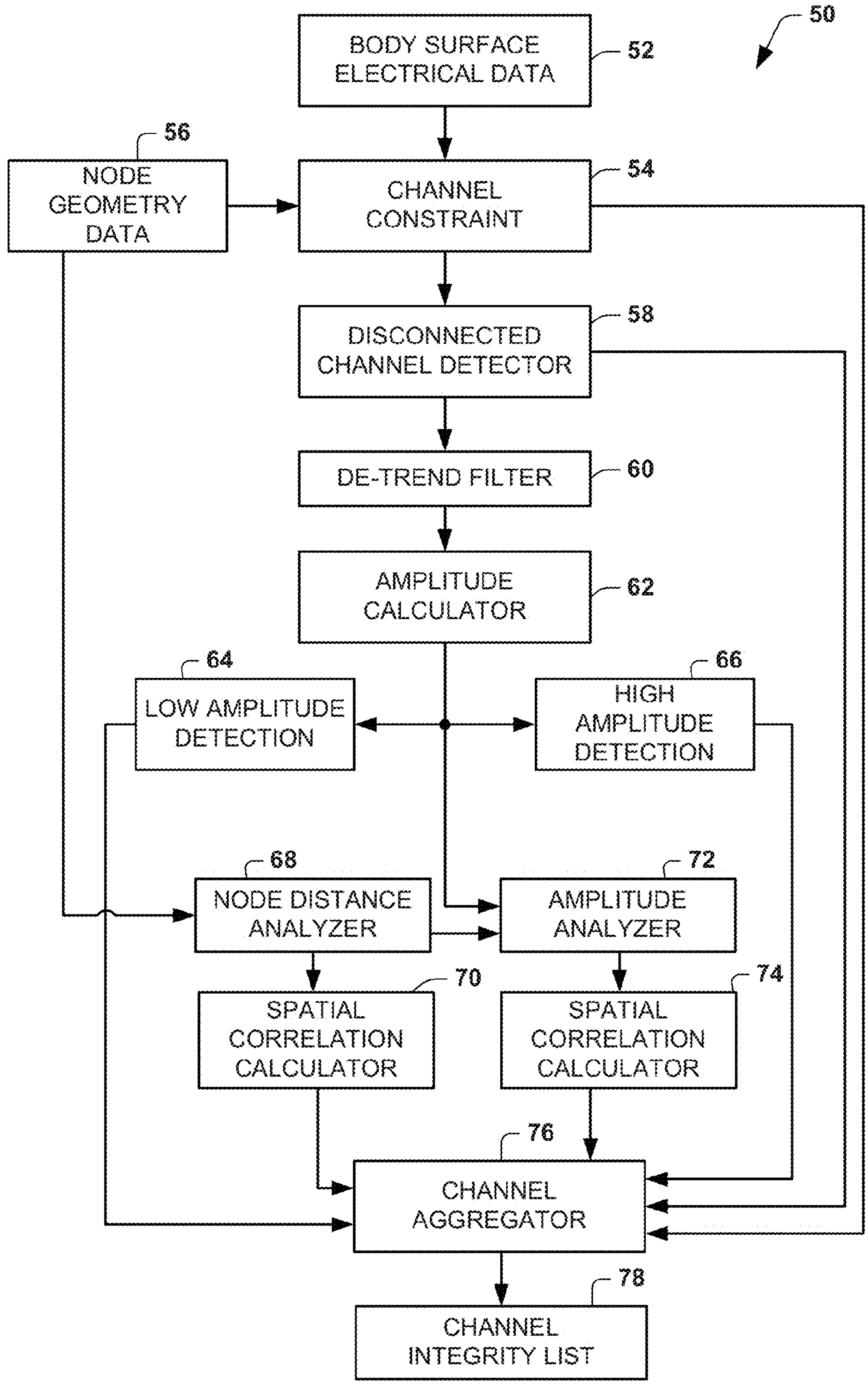
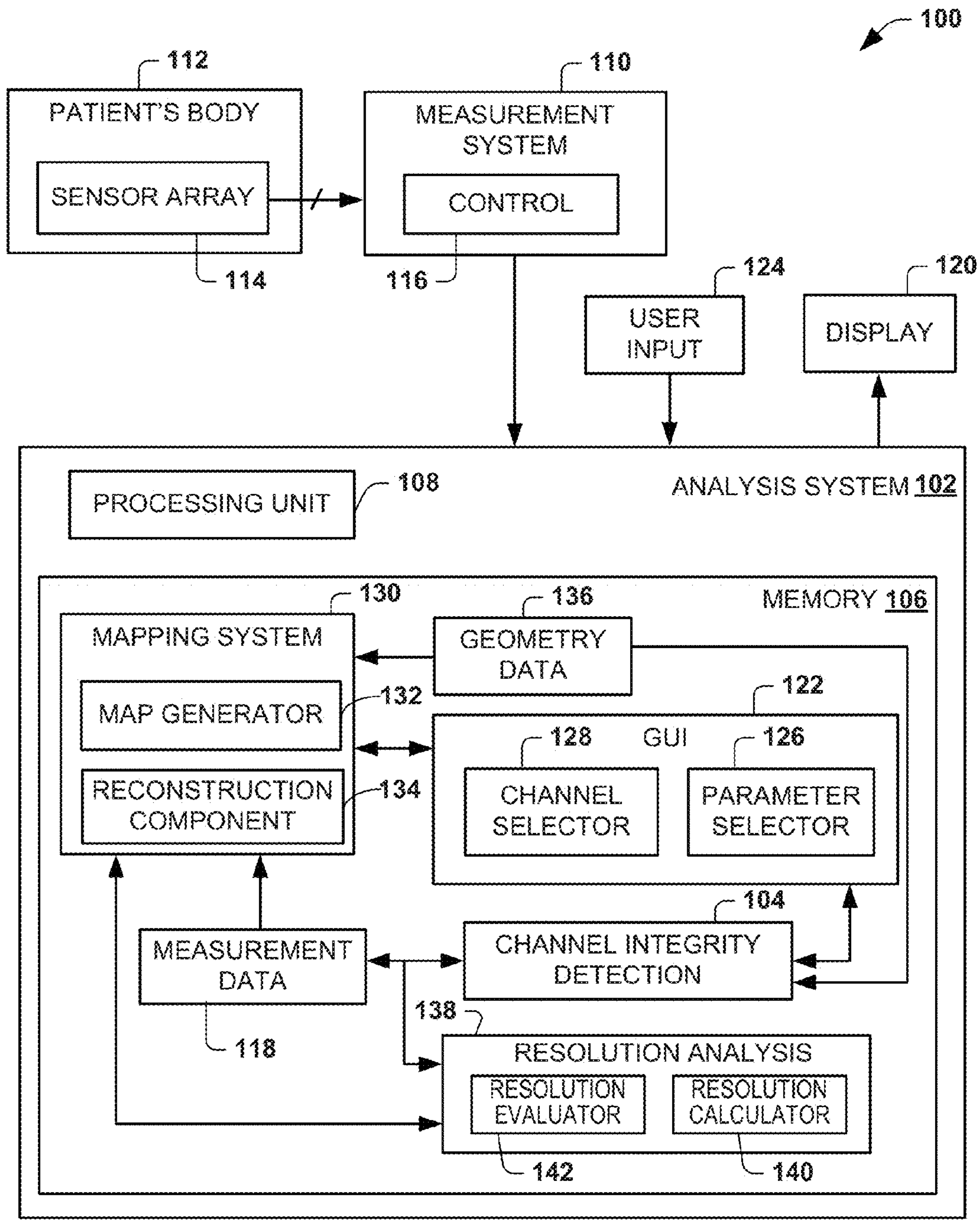

50
BODY SURFACE ELECTRICAL DATA
52
NODE GEOMETRY DATA
56
CHANNEL CONSTRAINT
54
DISCONNECTED CHANNEL DETECTOR
58
DE-TREND FILTER
60
AMPLITUDE CALCULATOR
62
LOW AMPLITUDE DETECTION
64
HIGH AMPLITUDE DETECTION
66
NODE DISTANCE ANALYZER
68
AMPLITUDE ANALYZER
72
SPATIAL CORRELATION CALCULATOR
70
SPATIAL CORRELATION CALCULATOR
74
CHANNEL AGGREGATOR
76
CHANNEL INTEGRITY LIST
78

FIG. 2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PATIENT'S BODY
SENSOR ARRAY
114
110
MEASUREMENT SYSTEM
CONTROL
116
124
USER INPUT
120
DISPLAY
PROCESSING UNIT
108
ANALYSIS SYSTEM 102
MEMORY 106
130
MAPPING SYSTEM
MAP GENERATOR
132
RECONSTRUCTION COMPONENT
134
136
GEOMETRY DATA
122
GUI
128
CHANNEL SELECTOR
126
PARAMETER SELECTOR
104
CHANNEL INTEGRITY DETECTION
MEASUREMENT DATA
118
138
RESOLUTION ANALYSIS
RESOLUTION EVALUATOR
RESOLUTION CALCULATOR
142
140

FIG. 3

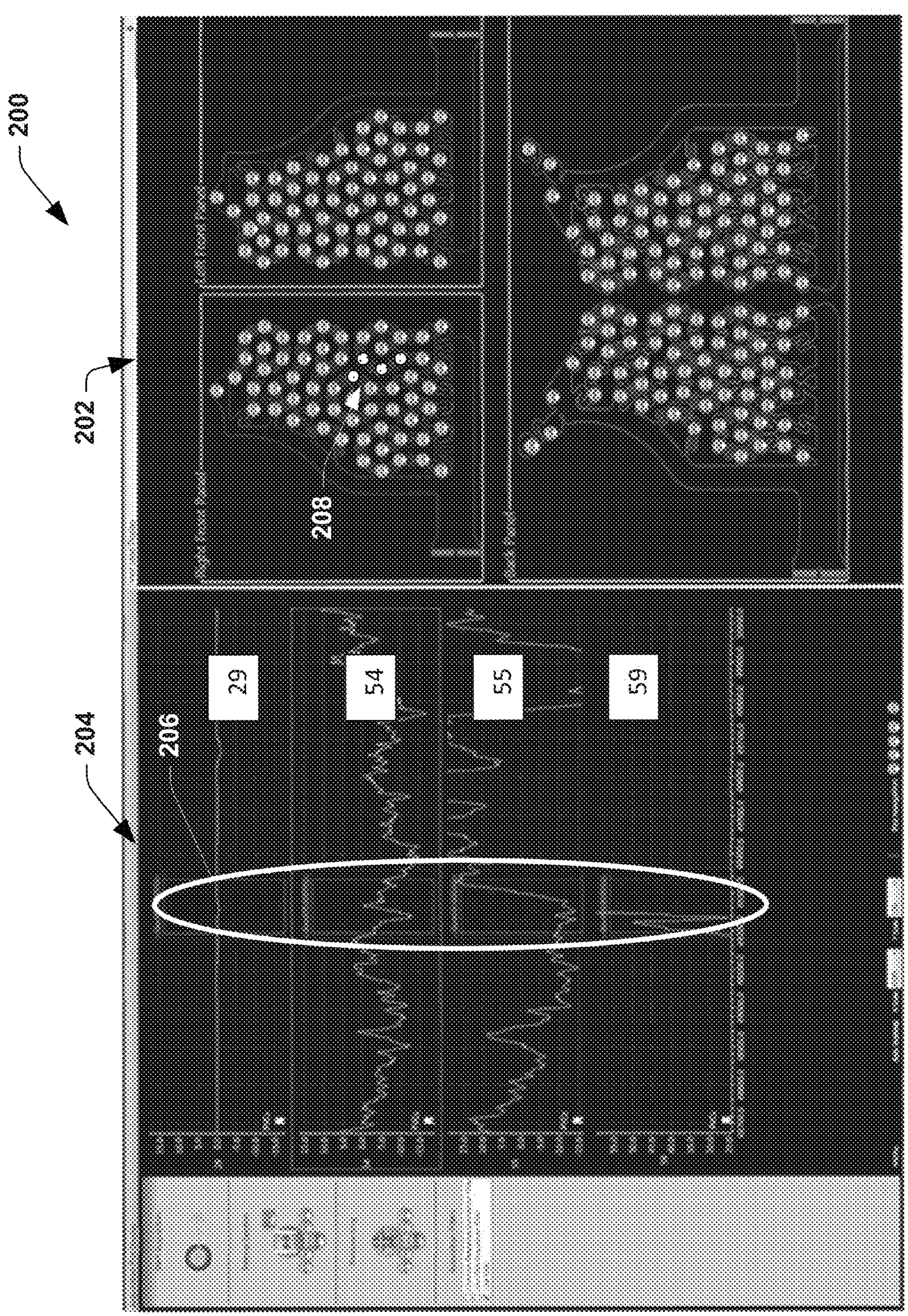


FIG. 4

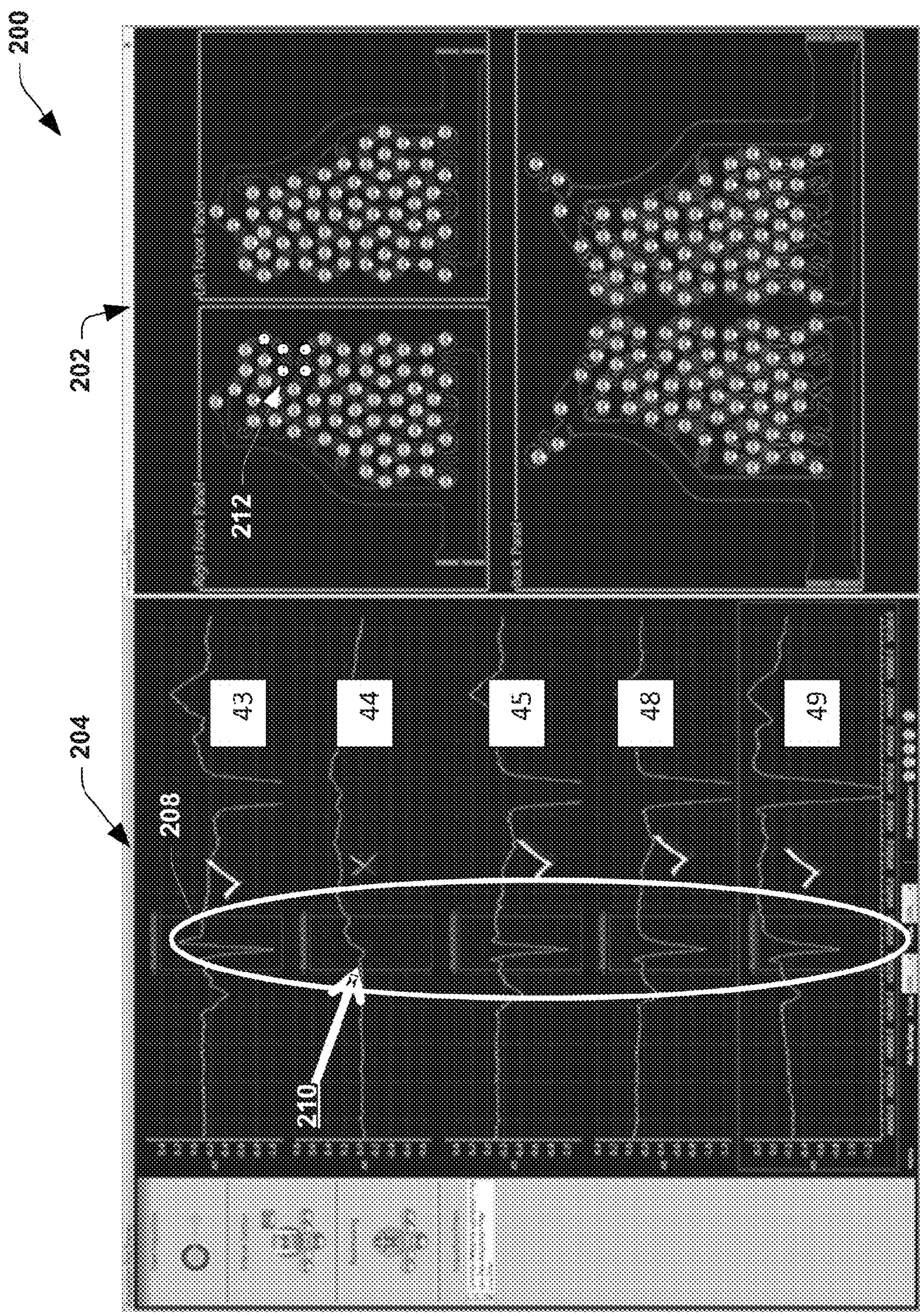


FIG. 5

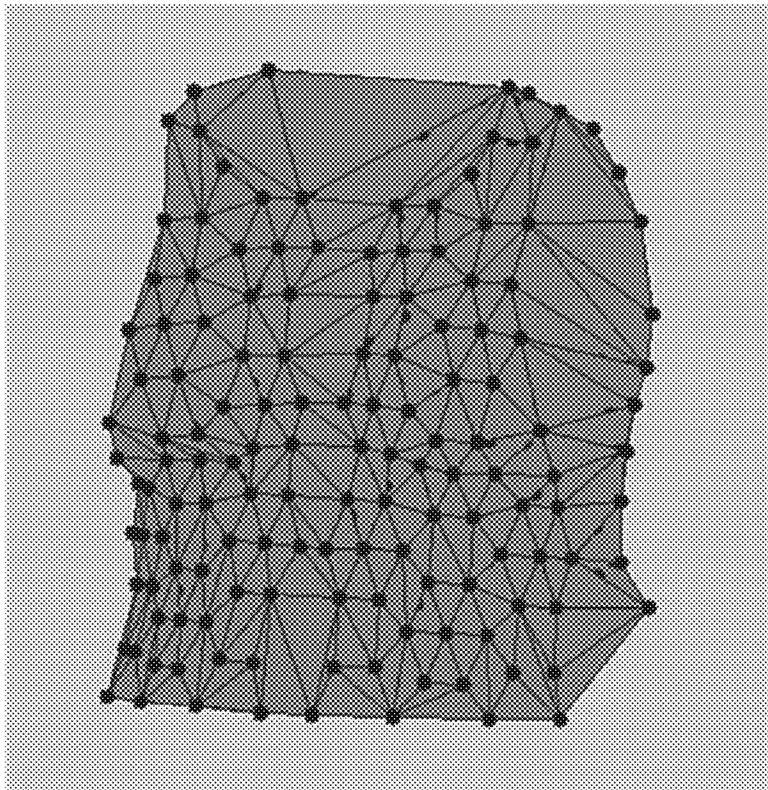


FIG. 6

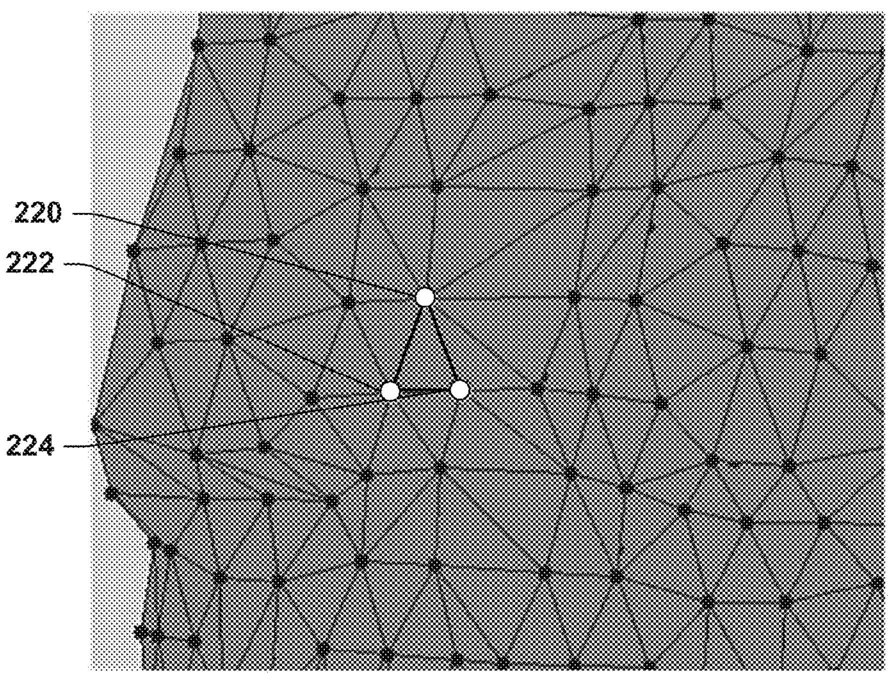


FIG. 7

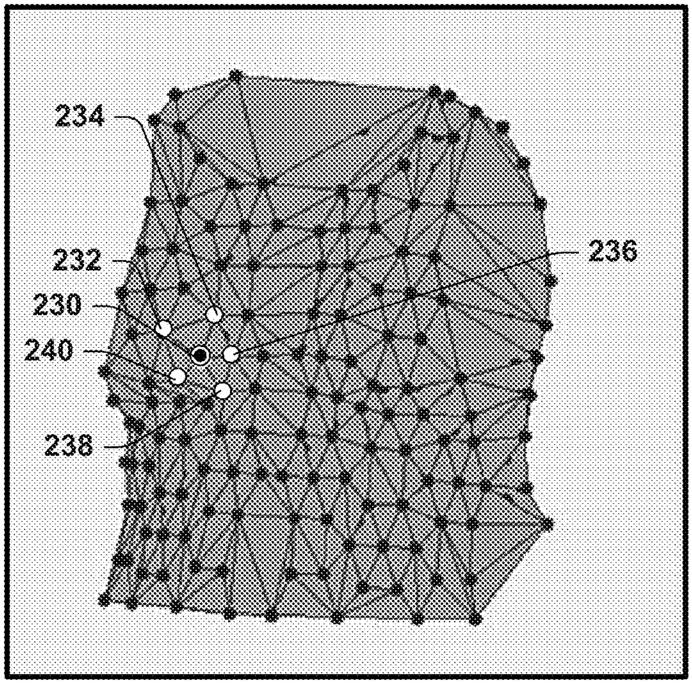


FIG. 8A

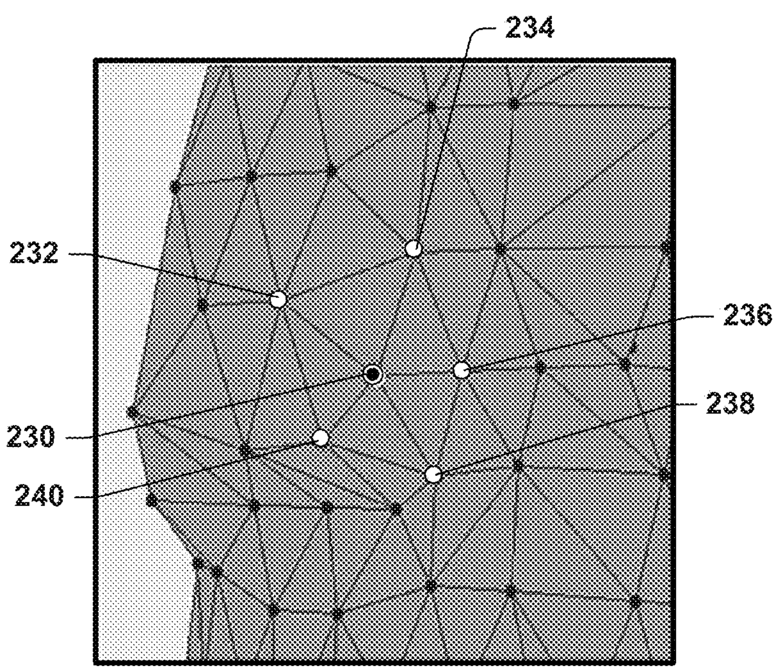
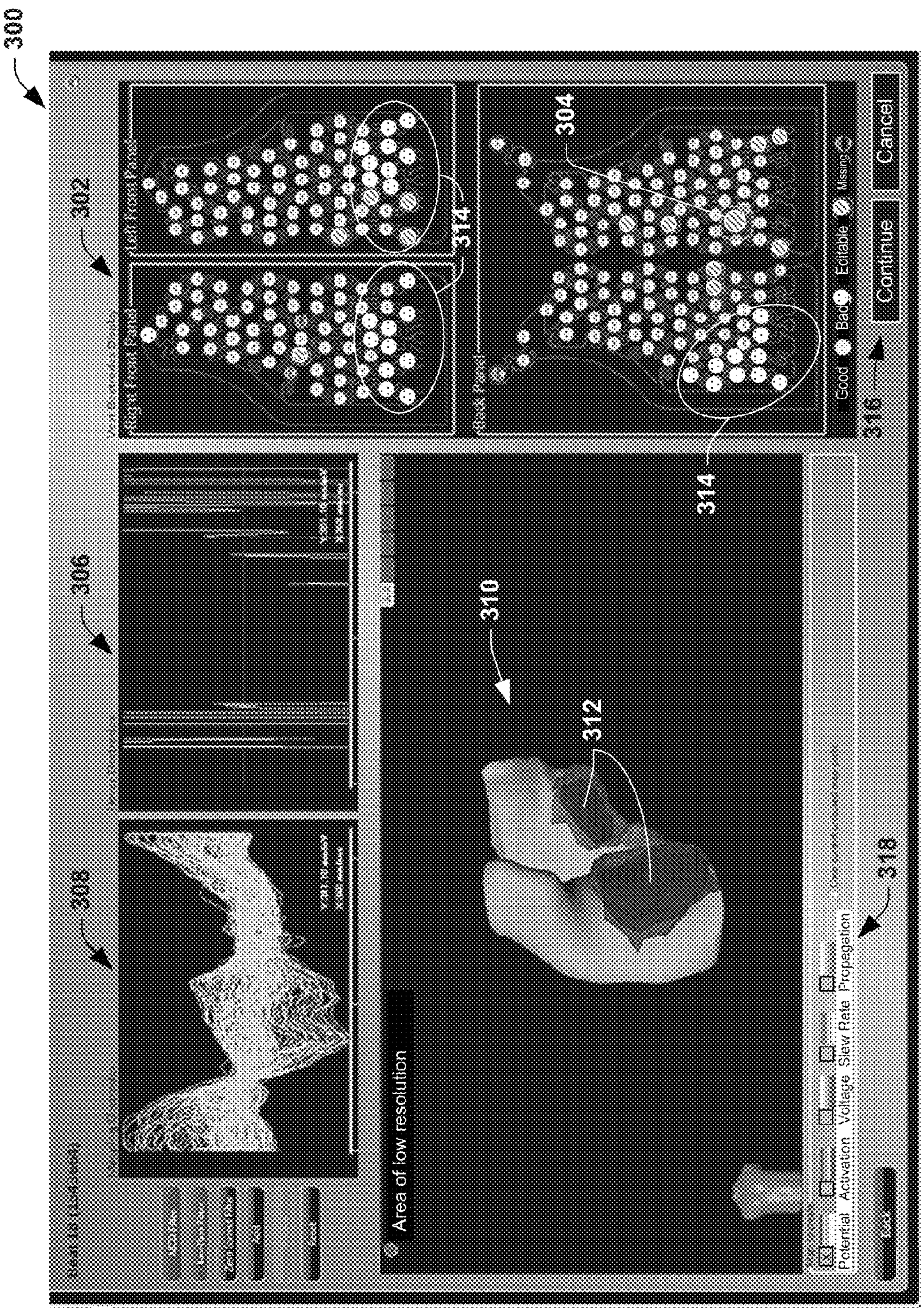


FIG. 8B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312
314
316
318
Left Front Panel
Back Panel
Good
Bad
Editable
Missing
Continue
Cancel
Area of low resolution
Potential
Activation
Voltage
Slew Rate
Propagation

FIG. 9

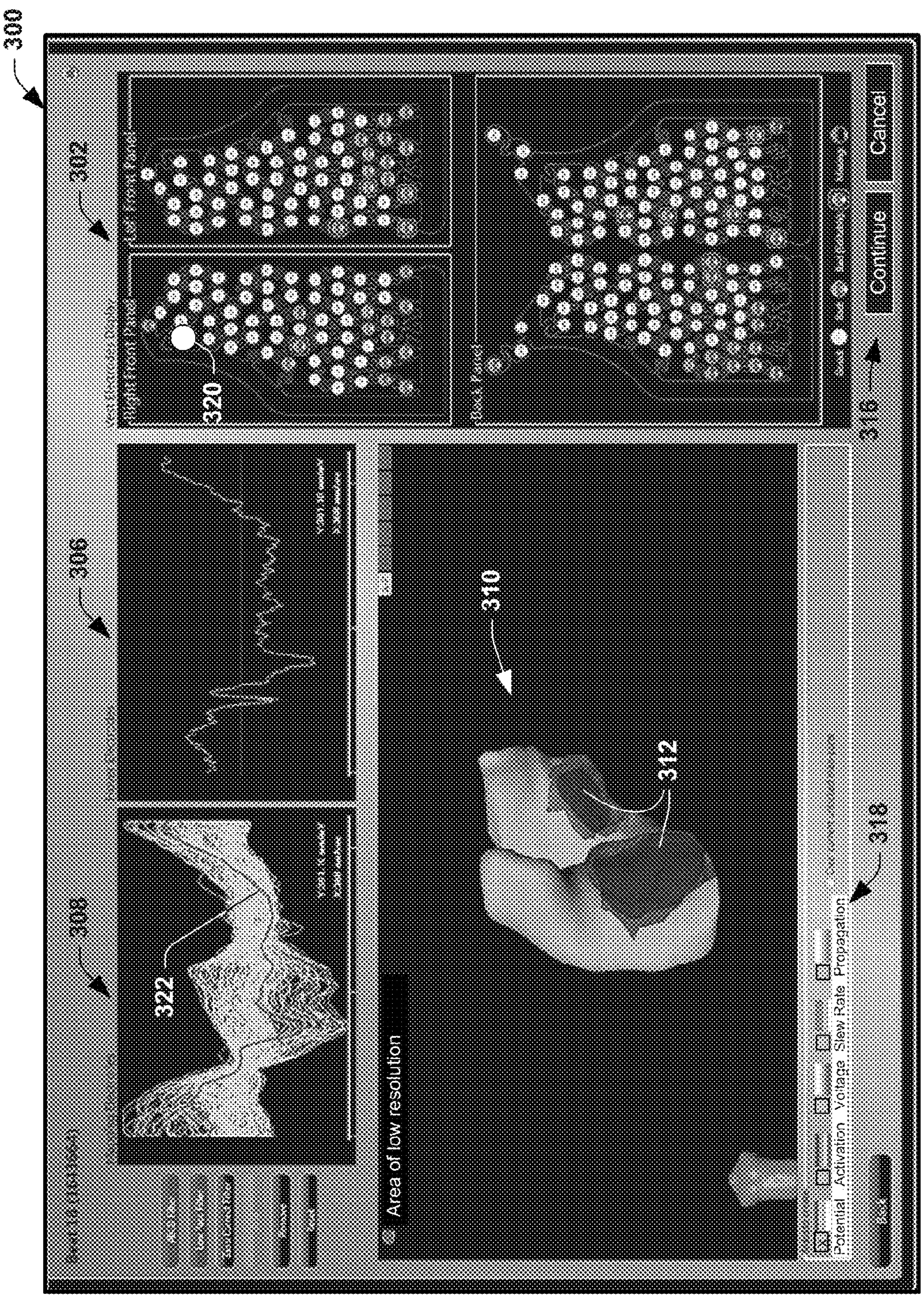
300
302
306
308
310
312
316
318
320
322
Area of low resolution
Continue
Cancel
Potential
Activation
Voltage
Slew Rate
Propagation

FIG. 10

CHANNEL INTEGRITY DETECTION

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application No. 61/644,746, filed May 9, 2012 and entitled Automatic Bad Channel Detection, which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

This disclosure relates to channel integrity detection.

BACKGROUND

In some examples, body surface electrical activity (e.g., ECG signals) can be sensed by an arrangement of electrodes. The sensed signals can be processed for a variety of applications, such as for body surface mapping or electrocardiographic mapping. Since these and other processing methods can depend on body surface potential data, the quality of data for each input channel can affect the quality of the output results based on signal processing. In some types of signal processing, the signal processing can be very sensitive to anomalies in the input channels. For instance, significant noise, such as line noise or large changes in amplitude, or other variations in the input channels could produce inaccurate results as well as overshadow the important physiological information. This could render the resulting outputs computed from such input channels non-diagnostic or uninterpretable.

SUMMARY

This disclosure relates to channel integrity detection, such as to mitigate undesirable effects of noisy input channels on further processing and analysis.

In one example, the channel integrity detection can be implemented as a non-transitory computer readable medium having instructions. The instructions can include a preprocessing stage to analyze input channel data for a plurality of input channels to detect channels having an integrity that is considered one of bad or good, each of the plurality of input channels corresponding to a respective one of a plurality of nodes. A first spatial similarity measurement function can compute a measure of similarity between the input channel data for each of the plurality of nodes and a set of neighboring nodes to identify a spatial correlated set of channels having an integrity that is considered one of bad or good. An amplitude analyzer function can determine a subset of channels meeting amplitude criteria. A second spatial similarity measurement function can compute, for each channel in the subset of channels meeting the amplitude criteria, a measure of similarity between the input channel data for each node and a set of neighboring nodes to identify an amplitude correlated set of channels having an integrity that is considered one of bad or good. A combiner can store output data representing the integrity of plurality of input channels based on the channels detected by the preprocessing stage, the channels identified by the spatial correlated set of channels and the channels identified by the amplitude correlated set of channels.

In another example, a computer-implemented method can include determining an amplitude for each of a plurality of input channels, corresponding to respective nodes. A measure of similarity can be computed between the input channel of each node and the input channel of its neighboring nodes. The method can also include comparing an amplitude for each node relative to other nodes to determine temporary bad channels. For each of the temporary bad channels, a measure of similarity can be computed between the input channel of each node and the input channel of its neighboring nodes. Channel integrity can then be identified based on the computed measures of similarity.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** depicts an example of a channel integrity detection system.

FIG. **2** depicts another example of a channel integrity detection system.

FIG. **3** depicts an example of an electrophysiological mapping system that can implement channel integrity detection.

FIG. **4** depicts an example of a graphical user interface demonstrating examples of high amplitude signals that can be identified via channel integrity detection.

FIG. **5** depicts an example of another graphical user interface demonstrating examples of low spatially correlated signals that can be identified via channel integrity detection.

FIG. **6** depicts a graphical representation of sensing nodes that can be distributed across a patient's body surface.

FIG. **7** depicts an enlarged view of a part of the nodes of FIG. **6** demonstrating a mesh configuration.

FIG. **8**A depicts a representation of a node mesh structure demonstrating a central node surrounded by a set of local neighboring nodes.

FIG. **8**B is an enlarged view of part of the mesh structure of FIG. **8**A further demonstrating the central node and its local neighboring nodes.

FIG. **9** depicts an example of a graphical user interface demonstrating additional signals that have been selected, a display of channel integrity as well as an example map that can be generated based on the signals detected by the sensing nodes.

FIG. **10** depicts another example of a graphical user interface demonstrating examples of channel signals, sensing node integrity and a resulting map that can be generated based on the input signals detected by the sensing nodes.

DETAILED DESCRIPTION

This disclosure relates to an apparatus, system or method that can determine channel integrity for a plurality of input channels. Each of the input channels can carry sensed electrical signals, such as electrophysiological signals from a patient. The sensed electrical signals for the respective channels can provide input channel data. In some examples, the approach disclosed herein can detect channels that may be detrimental to further signal processing sensitive to anomalous signals, such as line noise, large changes in amplitude or other variations in the input channels. The channel integrity detection disclosed herein thus enables detection and removal of channels determined to adversely affect such computations. In some examples, the detection and removal can be fully automated or semi-automated.

The channel integrity detection can perform pre-processing on the input channel data to identify certain types of faults or invalid channels, such as can include detecting disconnected sensing electrodes (e.g., saturated input channels), or other amplitude ranges (e.g., low and high amplitude ranges) that might adversely affect the signal processing. Additionally processing can be performed to compute a measure of spatial similarity (e.g., correlation) between the signals for a given node and its respective neighboring nodes. Signal channels having a low spatial correlation or otherwise uncorrelated relative to their respective neighbors can be identified as low integrity channels (e.g., also referred to herein as "bad channels"), and thus can be removed from further signal processing and analysis. Additional amplitude analysis can be performed for additional channel integrity detection. The amplitude analysis can be performed to identify outlier channels meeting certain amplitude conditions, on which additional similarity measurements can be performed to identify a further subset of channels that may have low channel integrity. Each of the identified low integrity channels, based on the preprocessing, the spatial similarity measurement and the amplitude analysis, can be combined to create a list of bad channels. The identified bad channels can be removed from further processing and signal analysis, such as to provide input channel data that includes the higher integrity channels.

As an example, the further processing and analysis can include reconstructing signals on a body surface based upon the input channel data (e.g., via an inverse solution). Additional calculations can be performed on the reconstructed data, such as to generate one or more graphical maps and characterize the reconstructed data. By removing such outlier channels from further processing, the approach can not only achieve improved accuracy in such further processing and analysis but also improves the system's workflow, such as by reducing preprocessing time.

Additionally, in some examples where a significant portion of the channels have been identified as "bad channels", a graphical map can be generated to identify the area of low resolution on a surface structure so that a user can determine if the affected area resides within a region of interest. A user can in turn select to continue in view of the identified low resolution area or make additional adjustments with respect to the sensing nodes that have been identified as "bad channels". A graphical user interface can also be provided to allow a user to selectively include or exclude one or more input channels from the analysis such as may be used to manually override the automatic removal of the identified bad channels.

FIG. **1** depicts an example of a channel integrity detection system **10** that can be utilized to provide an indication of channel integrity for a plurality of input channels. The channel integrity system **10** can be implemented as hardware, software (e.g., a non-transitory medium having machine readable instructions) or a combination of hardware and software. Signal information associated with each of the plurality of input channels can be provided by input channel data **12**. The input channel data **12** can correspond to a digital representation of the sensed analog signals, such as electrophysiology information. In some examples, the input channel data **12** can be provided by sensing electrodes that are placed on a body surface of the patient, which can be an internal body surface (e.g., invasive) or an external body surface (e.g., non-invasive) or a combination thereof.

By way of example, the input channel data **12** can represent signals acquired (e.g., in real time or previously) from a plurality of body surface electrodes that are distributed across a patient's body, such as the thorax. The electrodes can be distributed evenly across the entire thorax, for example. In other examples, the electrodes can be distributed across a selected surface area (e.g., a sensing zone), such as corresponding to electrodes that are configured to detect electrical signals corresponding to a predetermined region of interest. In some examples, the input channel data **12** can correspond to filtered input data, such as based on line filtering and other signal processing (e.g., offset correction, analog-to-digital conversion and the like) to remove selected noise components from the input signals of the respective channels.

The channel integrity detection system **10** can include preprocessing **14**, such as can include one or more method or function programmed to analyze the input channel data to identify certain types of outlier channels. In some examples, the preprocessing **14** can involve analysis of each channel without consideration of its neighboring channels. As used herein, the concept of neighbors, such a when referring to neighboring channels or nodes, refers to the spatial proximity of sensing electrodes or nodes that detect the input signals used to provide the input channel data **12**. Thus, the preprocessing **14** can relate to analysis of the input channel data for each channel by itself.

As a further example, the preprocessing **14** can include detecting disconnected channels, such as based on detecting the voltage or current on the respective channels that can identify the channel and its sensor as being disconnected or non-operational. The preprocessing **14** can also include detecting low amplitude signals that may have an amplitude below a predetermined low voltage threshold. The preprocessing **14** can also include evaluation of high amplitude signals, such as within a predetermined range or exceeding a high amplitude threshold. Each of the ranges and user threshold associated with the preprocessing can correspond to default values or can be user programmable, such as in response to a user input.

A similarity measurement function **16** can be programmed to compute a measure of similarity between input signals, based on the input channel data **12**, for each of the plurality nodes relative to a set of its local neighboring nodes. Each node's neighbors nodes can be determined from node geometry information, demonstrated in this example as node distance **22**. For example, the set of neighboring nodes for a given node can include a first adjacent set of neighboring nodes surrounding the given node. The similarity measurement function **16** can thus identify channel integrity for a spatially correlated set of channels. The set of channels and their integrity can correspond to good channels or bad channels or otherwise provide an identifier to distinguish between good and bad channels based on the spatial similarity measurement. In some examples, the similarity measurement function can determine if any channels are low correlated or uncorrelated channels and, based on such determination, identify a set of low integrity channels.

An amplitude analyzer **18** can evaluate the amplitude of each of the respective channels. Like the similarity measurement function **16**, the amplitude analyzer **18** can be performed on a set of channels excluding those that have been identified as low integrity channels by the preprocessing **14**. The amplitude analyzer **18** can determine a subset of higher amplitude outlier channels based on a comparison of channel amplitudes for at least a substantial portion of the other nodes. For example, the amplitude analyzer **18** can determine which node or nodes (if any) have an amplitude greater than a statistically significant amplitude value derived from evaluation of amplitudes for all relevant channels (e.g., one or more standard deviations from the mean amplitude). The resulting subset of statistically high amplitude channels identified by the analyzer **18** thus can be further processed by similarity measurement function **20** to compute a measure of similarity (e.g., a correlation) between the input channel data **12** for each node of the subset and its local neighboring nodes. Since if the high amplitude channels might be determined to be good channels if they correlate well with the other neighboring channels, they can be considered temporary bad channels in this analysis. The similarity measurement function **20** can identify which statistically high amplitude channels exhibit a low correlation relative to its neighbors and thus can be considered bad channels. Alternatively or additionally, the similarity measurement function **20** can identify which channels are high integrity channels.

In some examples, the amplitude analyzer **18** and the similarity measurement functions **16** and **20** can employ node distance **22** to determine neighboring nodes for each of the nodes being analyzed. Additionally, the inter-node distance can be used to further constrain the similarity measurement functions **16** and **20**. For example, if the node distance exceeds a predetermined distance, which can be a fixed value or be user programmable, such node can be excluded from analysis as neighboring node even if it is an actual spatial neighboring node. That is, the node distance **22** can constrain the measure of similarities to a spatial significant set of one or more nodes for each node that is processed by the amplitude analyzer **18** and the similarity measurement functions **16** and **20**.

The channel integrity detection system **10** can provide output channel data **24** to identify a set of one or more nodes having low integrity such that it should be excluded from subsequent analysis. The output channel data **24** can be provided in terms of a list of nodes indexed according to input channel that can be provided to subsequent processing blocks so that the corresponding data for a given channel is not utilized in subsequent signal processing and data analysis. As disclosed herein, the output channel data can be provided in terms of channel integrity that is considered bad, good, or can identify both bad and good channels. In some examples, a logic value (e.g., 0 or 1) can be used to specify if a channel is good or bad. In other examples, an integrity value can be calculated to provide range of values representing the integrity of each channel, such that the degree of goodness or badness can be characterized by the output channel data. In an ideal situation, there would be no bad channels and the input channel data **12** for all channels would be utilized for further processing and analysis. In practice, however, the channel integrity detection system **10** can identify low integrity channels that can be removed from further processing and analysis as to improve the results.

FIG. **2** depicts an example of a channel integrity detection system **50**. In the example of FIG. **2**, the channel integrity detection system **50** is demonstrated in the context of body surface electrical measurements that are represented by body surface electrical data **52** acquired for a respective patient over one or more time intervals. The body surface electrical data **52**, for example, can include measured electrical signals (e.g., surface potentials) obtained from a plurality of sensing electrodes distributed across the body surface of a patient. Similar to other examples disclosed herein, the distribution of electrodes can cover substantially the entire thorax of a patient or the sensing electrodes can be distributed across a predetermined section of the body surface such as configured for detecting electrical signals predetermined as being sufficient to detect electrical information corresponding to a predetermined region of interest for the patient's body. In other For example, a set of electrodes can be preconfigured to cover a selected region of the patient's torso for monitoring atrial electrical activity of one or both atrium of a patient's heart, such as for studying atrial fibrillation. In other examples other preconfigured sets of electrodes can be utilized according to application requirements, which can include invasive and non-invasive measurements.

The body surface electrical data **52** can be stored in memory of a computer. The body surface electrical data can represent real time information that is streaming in from sensing electrodes as data is acquired from a patient's body or it can be stored from a previous study. Regardless of the temporal nature of the electrical data **52**, the channel integrity detection system can improve accuracy of its further processing and analysis. Additionally, while the example of FIG. **2** is described in the context of channel detection for body surface electrical data, it is to be understood that the channel integrity detection, as disclosed herein, is equally applicable to other types of electrical signals including other types of electrophysiological signals (e.g., electromyography, electroencephalography, electrooculography, audiology and the like) as well as non-physiological electrical signals that may be monitored in a variety of other contexts.

An initial channel constraint **54** can be applied to the body surface electrical data **52**. The channel constraint **54**, for example can provide an index map that can be applied to the body surface electrical data to identify and remove channels that have been determined to be missing. For example, one or more electrodes can be physically removed from the sensing vest such that the information obtained by the channel is not relevant to the subsequent processing and analysis.

In another example where the body surface electrical data is to be mapped via inverse reconstruction to an anatomic envelope different from where the sensing has occurred, node geometry data **56** can be acquired for the sensing nodes. The node geometry data, for example, can identify the location of the sensing nodes (corresponding to sensing electrodes) in a respective correlated system. For example the node geometry data **56** can include a list of nodes, and neighbors for each node, such as can be produced by segmenting imaging data that has been acquired by an appropriate imaging modality. Examples of imaging modalities include ultrasound, computed tomography (CT), 3D Rotational angiography (3DRA), magnetic resonance imaging (MRI), x-ray, positron emission tomography (PET), fluoroscopy, and the like. Such imaging can be performed separately (e.g., before or after the measurements) utilized to generate the electrical data **52**. Alternatively, imaging may be performed concurrently with recording the electrical activity that is utilized to generate the patient electrical data **14**. The node geometry data **56** can also include coordinates (e.g., in three-dimensional space) for each of the nodes. Distances can be computed for neighboring nodes based on the coordinates (e.g., according to a distance metric, such as Euclidean distance). This can be stored in the node geometry data or it can be computed from such information by the system **50**. In other examples, the node geometry data **56** can be acquired by manual measurements between sensing nodes or other means (e.g., a digitizer).

The channel constraint **54** thus can be programmed to identify a given channel corresponding to a node that was not appropriately segmented (e.g., no location in 3-D space exists for the node). Thus missing channels and/or unsegmented channels can be flagged or otherwise removed from the body surface electrical data **52**. The channel constrained data can then be provided by the channel constraint function **54** for further analysis.

A disconnected channel detector **58** thus can operate on the constrained body surface electrical data (from channel constraint function **54**) to determine if any channels have been disconnected from the substrate, such as the patient's body from which the measurements have been acquired. As an example, the disconnected channel detector **58** can be configured to detect saturation of an input channel such as by monitoring the value of the electrical signal. If the value of the electrical signal for a channel exceeds a threshold value (e.g., about + or −500 mV) or has a predetermined value (e.g., 0 V) for a plurality of consecutive samples, the corresponding channel can be determined to be disconnected. As an example, a measurement system (e.g., measurement system **110** of FIG. **3**) to which the input channel signals are provided can be configured to saturate and obtain a predetermined value (e.g., about + or −500 mV) for a given channel if it loses contact with the body surface. In this way, the disconnected channel detector **58** can determine a saturated or disconnected channel which will be removed from further processing.

A de-trend filter **60** can be applied to the remaining body surface electrical data **52** (e.g., excluding bad channels that have been identified by the channel constraint **54** or the detector **58**). The de-trend filter **60**, for example, can be configured to remove the mean value or linear trend from each input channel (e.g., by FFT processing), which can remove baseline drift or other trending offsets from each respective channel. Such de-trending facilitates subsequent processing, including calculation of amplitude values for every signal channel. Additionally, by applying the de-trend filter **60** on the data provided by the disconnected channel detector **58** instead of before operation of the disconnected channel detector, the detection of saturated and disconnected channels is facilitated.

An amplitude calculator **62** is configured to compute a peak-to-peak amplitude on the de-trended input channel data for each of the channels. In the example where the body surface electrical data corresponds to electrocardiographic (ECG) data, the amplitude can be computed on de-trended ECG data. The computed amplitude values can be stored in memory with the body surface electrical data **52** associated with each of the channels. For example, the data **52** can be populated with an amplitude field according to the channel index with which the data is stored in memory.

A low amplitude detection function **64** can be programmed to determine if the calculated amplitude for each respective channel is below a predetermined low amplitude threshold. Each channel identified as a bad channel already (e.g., by channel constraint **54** and detector **58**) can be excluded from the low amplitude detection function **64**. For example the peak-to-peak amplitude of the signal for a given channel is less than the low voltage threshold, the given channels can be considered to be an extreme low amplitude and can be removed from further analysis (e.g., a bad or low integrity channel). The low amplitude threshold can be programmable or it can be set to a predetermined default value (e.g., about 1×10^{-8} mV).

A high amplitude detection function **66** can be programmed to detect channels having an amplitude that is greater than a typical body surface electrical signal (e.g., greater than a typical ECG signal). The high amplitude detection function **66** thus can be programmed to compare the amplitude calculated (e.g., by amplitude calculator **62**) for each channel relative to a high amplitude threshold. If the peak-to-peak amplitude of a given channel exceeds the high amplitude threshold, the channel can be identified in the electrical data **52** as a bad channel. The amplitude threshold can be programmable in response to user input or it can be set to a default value (e.g., about greater than 10 mV). The detection can be applied to each of the channels and the results stored in memory such as part of the body surface electrical data.

The system **50** can also include a node distance analyzer **68** that is programmed to quantify or characterize relative distance between the sensing nodes that are distributed across the body surface. For example, it has been determined that if the distance between neighboring nodes exceeds a certain distance, a comparison between neighboring channels may no longer be valid. As a result, the node distance analyzer **68** can programmed to determine if the distance between neighboring nodes exceeds distance threshold. The distance threshold can be a default value or it can be programmable to a desired value in response to a user input. The node distance analyzer **68** can analyze the nodes based on the node geometry data **56**. As mentioned above, the node geometry data **56** can be obtained by a segmentation process performed on imaging data or other means.

The node distance analyzer **68** thus can be used to constrain spatially comparative processing, as disclosed herein, to include only those sensors and its neighbors that are within a prescribed proximity of each other. As a result, the likelihood of identifying a channel as a 'bad channel' can be reduced when a morphological change is due to distance between respective nodes instead of a spatial non-correlation between the respective input signals of such nodes.

An identification of the set of nodes and neighboring nodes that exceed the maximum node distance can be provided as an input to a spatial correlation calculator **70** and an amplitude analyzer **72**. The spatial correlation calculator **70** can be programmed to calculate correlation coefficients between the input signals for each node not already excluded and its local neighboring nodes. The spatial correlation calculator **70** thus computes correlation coefficients from a cross correlation between a given central node and its local neighboring nodes, as constrained by the maximum node distance. The correlation coefficients between a central node and its neighboring nodes can be combined and compared relative to a correlation threshold (e.g., correlation cutoff value) to determine whether the signals are spatially non-correlated or uncorrelated. For example, the spatial correlation calculator **70** can be configured to compute a cross correlation between the central node and each of its neighbors that yields a coefficient value, and a mean correlation value can be computed for each node such as to provide a single correlation value for each node. The minimum mean correlation node can be removed from further analysis, including that to be performed by the amplitude analyzer **72** and following correlation analysis. The spatial correlation calculator **70** thus compares the correlation coefficients relative to the correlation threshold (e.g., a correlation cutoff value) and recalculates mean correlation values. The spatial correlation calculator **70** can repeat this process can continue until the minimum mean correlation value exceeds the correlation cut off value. If any channel had only one remaining neighbor for comparison, it can be not considered to not be a low integrity channel by the spatial correlation calculator **70**.

The amplitude analyzer **72** is programmed to identify a proper subset of channels having a peak-to-peak amplitude greater than a statistically significant portion of the nodes. For example, the amplitude analyzer **72** can perform a histogram analysis of the peak-to-peak amplitude to detect outliers among each of the remaining channels (e.g., channels not already identified as bad channels). Those channels in the input data set provided to the amplitude analyzer that exceed the high amplitude threshold can be provided to a spatial correlation calculator **74**. The high amplitude threshold can be determined from analysis of all the signal channels, such as based on an amount of variation (e.g., a percentage or a multiple of a standard deviation) greater than mean amplitude of the signals.

The spatial correlation calculator **74** can perform the same correlation as the spatial correlation calculation **70** or it can be different. For example, the spatial correlation calculator **74** can compute correlation coefficients based on performing a cross correlation between the signals for each respective node and its local set of neighboring nodes. As mentioned above, nodes exceeding the maximum node distance are not included in this analysis. Additionally, low amplitude channels and high amplitude channels as well as disconnected and channels otherwise constrained are also not included in the analysis performed by the spatial correlation calculator **74**. As an example, the spatial correlation calculator **74** can require a larger amount of correlation than that required by the analysis implemented by the spatial correlation calculator **70** (e.g., the correlation threshold of calculator **70**). That is the cross correlation performed by the spatial correlation calculator **74** can employ a more strict correlation threshold than that employed by the spatial correlation calculator **70**.

A channel aggregator **76** can be configured to combine the list of bad channels detected by the analyzer components of the channel integrity detection system **50**, such as including the channel constraint function **54**, the disconnected channel detector **58**, the low amplitude detection function **64**, the high amplitude detection function **66**, the spatial correlation calculator **70** and the spatial correlation calculator **74**. The channel aggregator **76** in turn can provide a channel integrity list that can be utilized to exclude such channels from subsequent analysis. In other examples, the channel integrity list **78** represent good channels on which subsequent analysis is to be performed. In yet another example, the channel integrity list could provide an indication of both good channels and bad channels. In still another example, a channel integrity list could provide a quantified value representing a channel integrity for each of the respective nodes based upon the analysis performed by the channel integrity detection system **50**. Regardless of the contents and type of information in the channel integrity list, the information can be stored in memory in conjunction with the body surface electrical data **52** for further processing and analysis.

By way of further example, other inputs to and the channel integrity detection system **50** can include variables demonstrated in the following table. As disclosed herein some of the variables can be set to default values or be user programmable. The outputs from the integrity detection system **50** can include variables representing a bad (and/or good) channel list. A list of saturated or disconnected channels can also be provided.

Variable Name	Description
triangles	triangular mesh node connection list (part of the geometry data 56)
vertices	x, y, z coordinates of each node point (part of or determined from geometry data 56)
dataOrig	channel input data (electrical data 52)
ccCutOff	Correlation coefficient maximum value for bad channels (used by correlation calculator 70)
ampCutoffSDMultiplier	Amplitude standard deviation multiplier (used by amplitude analyzer 72)
maxNodeDistValue	Maximum node distance (used by node distance analyzer 68)

-continued

Variable Name	Description
badChannelZero	Previously detected bad channels - saturated (provided by channel constraint 54)
channelIndices	channel indices which references non missing channels
maxNodeDistMultiplier	Maximum node distance standard deviation multiplier (used by amplitude analyzer 72)
ccCutoffAmplitude	Amplitude correlation coefficient maximum value for bad channels (used by correlation calculator 74)

FIG. **3** depicts an example of a system **100** that can be utilized for acquiring electrical activity sensed from a patient **108** and for analyzing the sensed electrical activity. In some examples, the sensed electrical activity can be used to generate one or more graphical representations (e.g., graphical maps of electroanatomic activity) based on the sensed electrical activity, such as for a region of patient anatomy. The system **100** can include an analysis system **102** that employs a channel integrity detection **104** as disclosed herein.

The analysis system **102** can be implemented as including a computer, such as a laptop computer, a desktop computer, a server, a tablet computer, a workstation or the like. The analysis system **102** can include memory **106** for storing data and machine-readable instructions. The memory **106** can be implemented, for example, as a non-transitory computer storage medium, such as volatile memory (e.g., random access memory), non-volatile memory (e.g., a hard disk drive, a solid-state drive, flash memory or the like) or a combination thereof.

The analysis system **102** can also include a processing unit **108** to access the memory **106** and execute the machine-readable instructions stored in the memory. The processing unit **108** could be implemented, for example, as one or more processor cores. In the present examples, although the components of the analysis system **102** are illustrated as being implemented on the same system, in other examples, the different components could be distributed across different systems and communicate, for example, over a network.

The system **100** can include a measurement system **110** to acquire electrophysiology information for a patient **112**. In the example of FIG. **3**, a sensor array **114** includes one or more electrodes that can be utilized for recording patient electrical activity. As one example, the sensor array **114** can correspond to an arrangement of body surface electrodes that are distributed over and around the patient's thorax for measuring electrical activity associated with the patient's heart (e.g., as part of an ECM procedure). In some examples, there can be about 200 or more sensors (e.g., about 252 sensors) in the array **114**, each sensor corresponding to a node that defines a respective channel. An example of a non-invasive sensor array that can be used is shown and described in International application No. PCT/US2009/063803, which was filed 10 Nov. 2009, and is incorporated herein by reference. This non-invasive sensor array corresponds to one example of a full complement of sensors that can include one or more sensing zones. As another example, the sensor array **108** can include an application-specific arrangement of electrodes corresponding to a single sensing zone or multiple discrete sensing zones, such as disclosed in International application No. PCT/US2012/059957, which was filed 12 Oct. 2012, and is incorporated herein by reference. Additionally or alternatively, the sensor array **114** can include invasive sensors that can be inserted into the patient's body.

The measurement system **110** receives sensed electrical signals from the corresponding sensor array **108**. The measurement system **110** can include appropriate controls and signal processing circuitry (e.g., filters and safety circuitry) for providing corresponding electrical measurement data **118** that describes electrical activity for each of a plurality of input channels detected by the sensors in the sensor array **114**.

The measurement data **118** can be stored in the memory **106** as analog or digital information. Appropriate time stamps and channel identifiers can be utilized for indexing the respective measurement data **118** to facilitate the evaluation and analysis thereof. As an example, each of the sensors in the sensor array **114** can simultaneously sense body surface electrical activity and provide corresponding measurement data **118** for one or more user selected time intervals.

The analysis system **102** is configured to process the electrical measurement data **118** and to generate one or more outputs. The output can be stored in the memory **106** and provided to a display **120** or other type of output device. As disclosed herein, the type of output and information presented can vary depending on, for example, application requirements of the user.

As mentioned, the analysis system **102** is programmed to employ channel integrity detection methods **104** to improve the accuracy in processing and analysis performed by the analysis system. The channel integrity detection **104** can, for example, be implemented to perform any combination of the channel integrity detection functions and methods disclosed herein (see, e.g., FIGS. **1** and **2** and the corresponding description). The channel integrity detection **104** thus can compute an indication of which input channels are bad (or good) based on signal processing on the measurement data **118**. The resulting channel integrity data provided by the detection methods **104** can be stored in the memory **106**, such as in conjunction with the measurement data **118**. In this way, bad channels can be removed automatically or selectively for further processing and analysis.

In some examples, the channel integrity detection **104** can interface with a graphical user interface (GUI) **122** stored as executable instructions in the memory **106**. The GUI **122** thus can provide an interactive user interface, such that the thresholds and related parameters utilized by the channel integrity detection **104** can be set in response to a user input **124**. The GUI **122** can provide data that can be rendered as interactive graphics on the display **120**. For example, the GUI **122** can generate an interactive graphical representation that differentiates between good and bad channels (e.g., a graphical representation of the sensor array **114** differentiating graphically or otherwise between bad and good channels).

In the example of FIG. **3**, the GUI includes a parameter selector **126** that can be employed to program channel integrity parameters (e.g., thresholds and constraints) implemented by the channel integrity detection **104**. In some examples, default values can be utilized unless modified in response to a user input, such as disclosed herein.

The GUI **122** can also include a channel selector **128** programmed to select and deselect channels in response to a user input. The channel selector **128** can be employed to manually include or exclude selected channels. For instance, the GUI **122** can indicate (e.g., by graphical and/or textual indicators) on the display **120** which channels are missing channels to be excluded, a suggested set of channels that are to be excluded but can be editable via the GUI, and a set of channels considered to be high integrity (e.g., good) channels and are also editable via the GUI. A user can thus employ the channel selector **128** of the GUI **122** to include a bad channel that has been identified for removal or exclude a good channel that is identified for inclusion.

As a further example, the analysis system **102** can include a mapping system **130** that is programmed to generate electroanatomical map based on the measurement data **118**, namely based on the measurement data for the channels determined to have a sufficient integrity (i.e., excluding bad channels). The mapping system **130** can include a map generator **132** that is programmed to generate map data representing a graphical (e.g., an electrical or electroanatomic map) based on the measurement data **118**. The map generator **132** can generate the map data to visualize such map via the display **120** spatially superimposed on a graphical representation of an anatomical structure (e.g., the heart).

In some examples, the mapping system **130** includes a reconstruction component **134** programmed to reconstruct heart electrical activity by combining the measurement data **118** with geometry data **136** through an inverse calculation. The inverse calculation employs a transformation matrix and to reconstructs the electrical activity sensed by the sensor array **114** on the patient's body onto an anatomic envelope, such as an epicardial surface, an endocardial surface or other envelope. Examples of inverse algorithms that can be implemented by the reconstruction component **134** are disclosed in U.S. Pat. Nos. 7,983,743 and 6,772,004.

The reconstruction component **134**, for example, computes coefficients for a transfer matrix to determine heart electrical activity on a cardiac envelope based on the body surface electrical activity represented by the electrical measurement data **118**. Since the reconstruction onto the envelope can be sensitive to ingress and other noise on the respective input channels, the channel integrity detection **104** helps to remove data for channels that would likely adversely affect the process. Additionally, the reconstruction component **134** can utilize interpolated measurement data computed for the identified bad channels. Such interpolation for a given channel can be calculated based on signal values determined from its neighboring nodes, for example. The possible effect of such interpolation on the resolution provided in a graphical electroanatomic map can vary depending on the quantity and spatial distribution of bad channels, as disclosed herein.

The map generator **132** can employ the reconstructed electrical data computed via the inverse method to produce corresponding map of electrical activity. The map can represent electrical activity of the patient's heart on the display **120**, such as corresponding to a map of reconstructed electrograms (e.g., a potential map). Alternatively or additionally, an analysis system **102** can compute other electrical characteristics from the reconstructed electrograms, such as an activation map, a repolarization map, a propagation map or other electrical characteristic that can be computed from the measurement data. The type of map can be set in response to the user input **124** via the GUI **122**.

By way of further example, the patient geometry data **136** can be acquired using nearly any imaging modality (e.g., x-ray, computed tomography, magnetic resonance imaging, ultrasound or the like) based on which a corresponding representation can be constructed, such as described herein. Such imaging may be performed concurrently with recording the electrical activity that is utilized to generate the measurement data **118** or the imaging can be performed separately. As another example, the geometry data **136** can correspond to a mathematical model of a torso that has been constructed based on image data for the patient's organ. A generic model can also be utilized to provide the geometry data **136**. The generic model further may be customized (e.g., deformed) for a given patient, such as based on patient characteristics include size image data, health conditions or the like. Appropriate anatomical or other landmarks, including locations for the electrodes in the sensor array **108** can also be represented in the geometry data **116**, such as by performing segmentation of the imaging data. The identification of such landmarks can be done manually (e.g., by a person via image editing software) or automatically (e.g., via image processing techniques).

The analysis system **102** can also include a resolution analysis function **138** to determine the impact on resolution of analysis performed by the mapping system **130** based on the identified bad channels. As an example, the resolution analysis function **138** can include a resolution calculator **140** programmed to compute resolution for data that is reconstructed onto a prescribed surface (e.g., by the reconstruction component). As mentioned, the surface can include a surface envelope such as can include an anatomical surface, a surface of a model or a combination of a model and anatomical structure onto which electrical data is to be reconstructed, as represented by the geometry data **136**. In some examples, the surface can include an epicardial surface or an endocardial surface of a patient's heart, and further may include an entire surface or a selected region of interest.

A resolution evaluator **142** can analyze the computed resolution over the surface, such as by comparing the computed resolution relative to a threshold. The threshold can be utilized to determine an area of low resolution that would be adversely affected by the identified bad channels. The area of low resolution, for example, can be provided to the map generator **132** and, in turn, be utilized to construct a graphical map that can be graphically presented to a user on the display **120**. The user further can be provided an opportunity to select to continue or make other adjustments to the sensor array **114** in an effort to improve the channel integrity. In other examples, a user can select to proceed with analysis with the understanding that certain areas of the reconstructed data may occupy areas of low resolution and thus could contain associated inaccuracies. Such inaccuracies, however, may be insignificant when a desired region of interest resides outside the area of low resolution.

FIG. **4** depicts an example of a GUI **200** that includes a first display portion **202** that includes a graphical depiction of a sensor array illustrates sensing nodes. Another portion of the GUI **200** includes a display portion **204** representing a set of electrical signals **206**. The GUI **200** can correspond to the GUI **122** of FIG. **3**, for example. The electrical signals **206** demonstrated in FIG. **4** include signals for a selected set of channels **208** identified as channels **29**, **54**, **55** and **59** of the set of channels. The peak-to-peak amplitude of the channel **54** is approximately 13 mV. The peak-to-peak amplitude of the third channel **55** is approximately 30 mV. The first channel has an approximate peak-to-peak amplitude of about 30 mV. Each of the channels **54**, **55** and **59** are examples of high amplitude channels that would be detected by the high amplitude detection function of the channel integrity detection method as disclosed herein.

FIG. **5** depicts an example of the GUI **200** from FIG. **4** demonstrating signals **210** for a different selected set of channels **43**, **44**, **45**, **48** and **49**, demonstrated at **212**. Based on the spatial measurement functions disclosed herein, it can be determined that each of the channels **43**, **44**, **45**, **48**, and **49** exhibits similar morphology, and thus would be spatially well correlated. However, the signal for channel **44** has a morphology not similar to its respective neighboring channels, and thus can be computed by the channel integrity detection method as a low integrity or bad channel.

As an example, body surface electrophysiological channels are related spatially by the connections formed between each sensing node and its corresponding surrounding nodes. As shown in the example of FIGS. **6** and **7**, the spatial relationship between nodes can be represented by a triangular mesh.

As a further example, geometry data (e.g., data **56** of FIG. **2** and data **136** of FIG. **3**) for a segmented image set for a patient while a sensor array of electrodes is positioned on the patient body can provide data representing each node's spatial location (e.g., an x, y, z coordinate position). The geometry data can also provide a corresponding triangular mesh connection (e.g., node number triplets for the formation of each mesh triangle) for each node. For example, in FIG. **7**, the nodes **220**, **222**, and **224** (highlighted) were connected by a corresponding triangulation triplet. The triangular connections across the body surface form a triangular mesh which can be used to provide the body surface information for subsequent processing, such as for inverse problem calculations, as disclosed herein.

Each node point on the torso thus is connected by the triangular mesh to one or more neighboring node points. These surrounding nodes are considered the node's "neighbors". An example center node **230** and its local neighboring nodes **232**, **234**, **236**, **238** and **240** are shown in FIGS. **8**A and **8**B. In one example of comparative calculations (e.g., by the similarity measurement **16**, amplitude analyzer **18** and similarity measurement **20** of FIG. **1**), the center node (e.g., node of interest) **230** is only compared relative to its adjacent neighboring nodes. In addition to the calculating the neighboring nodes, the node distances between each node and its specific neighbors are calculated (e.g., by the node distance function **22** of FIG. **1** or node distance analyzer **68** of FIG. **2**). As disclosed herein, the node distances can be used to discriminate poor node comparisons based on distance. While this example includes only an immediately adjacent set of neighboring nodes **232**, **234**, **236**, **238** and **240** as neighbors (e.g., which form a neighborhood of nodes), other degrees of proximity can be utilized in other examples. Additionally, the distance between each center node and its neighboring nodes can be utilized to provide a weighting applied to each correlation between the neighboring nodes. As a result, a more accurate correlation that varies as a function of distance can be utilized in the correlation between neighboring channels.

FIGS. **9** and **10** demonstrate examples of a GUI **300**, such as can correspond to the GUI **122** of FIG. **3**. In the example of FIG. **9**, the GUI **300** includes a plurality of display areas, at least some or all of which can include interactive GUI elements that can activate functions or methods in response to a user input. For example, an interactive electrode display area **302** includes a graphical representation of sensing nodes (e.g., electrodes of a sensor array), such as can correspond to electrodes distributed on a patient's body as disclosed herein. A scale is provided to inform the user of different levels of channel integrity, such as can include 'Good' channels, bad channels, bad but editable channels and missing channels. For example, the scale can utilize different colors, graphical indicia, text or any combination thereof to differentiate channel integrity that has been determined for each such channel, such as shown in FIG. **9**. In this example one of the nodes **304** has been selected and its corresponding signal is presented in display area **306**. Any number of one or more nodes can be selected to provide its signal in the display area **306**. An adjacent display area **308** includes waveforms for each of the electrodes that have not been removed by the channel integrity detection or that has been removed (e.g., an editable channel) but has been reactivated by the user.

Also demonstrated in FIG. **9** is a graphical map **310**. In this example, the graphical map **310** includes a graphical representation (e.g., via color coding) of one or more areas of low resolution, demonstrated at **312**. The area of low resolution, for example, can be determined by a resolution analysis method (e.g., resolution analysis method **138** of FIG. **3**) in conjunction with reconstruction of the sensed signals to a surface (e.g., the cardiac surface). Thus, the graphical map **310** can display the effect that the identified bad channels will have on the overall resolution of inverse calculations. In this example, the area of low resolution is the result of several bad channels, highlighted at **314**, near the low edge of each panel of the array of electrodes. A user thus has an opportunity to cancel the process and adjust the sensing electrodes or the user can select to continue (e.g., via GUI elements **316**) the process.

The GUI **300** also includes GUI elements **318** that can be utilized to select what type of map will be generated (e.g., by map generator **132** of FIG. **3**) and presented in the map **310** in response to a user input. Examples of maps that can be created can include a potential map, an activation map, a voltage map, a slew rate map and a propagation map. Other maps could also be generated.

FIG. **10** depicts another example of the GUI **300** in which the same reference characters refer to the same parts introduced with respect to FIG. **9**. In the example of FIG. **10**, a given node **320** has been selected in response to a user input. The corresponding waveform is presented in the display area **306**. The resulting mapped electrode following reconstruction for each of the good electrodes is demonstrated in display area **308**. Additionally, since the selected node in this example has been determined (e.g., by channel integrity detection method **104** of FIG. **3**) to be a good channel, its reconstructed waveform is highlighted (e.g., graphically differentiated) from the other reconstructed waveforms in the display area **308**, as shown at **322**. Similar to FIG. **9**, the map **310** includes areas of low resolution **312** resulting from the impact of channels that have been determined to be bad channels (e.g., by channel integrity detection method **104** of FIG. **3**).

In view of the foregoing, an automatic bad channel detection method has been disclosed to improve accuracy and user experience. The approach disclosed herein thus can enhance the user interaction and increase the ease of beat-by-beat analysis. The bad channel detection methods and systems can be implemented to identify and remove high amplitude and low spatially correlated signal channels. The remaining channels can be utilized to reconstruct electrical activity on a surface envelope (e.g., epicardial or endocardial electro grams) via potential-based inverse electrocardiography algorithms.

As will be appreciated by those skilled in the art, portions of the invention may be embodied as a method, data processing system, or computer program product. Accordingly, these portions of the present invention may take the form of an entirely hardware embodiment, an entirely software embodiment, or an embodiment combining software and hardware. Furthermore, portions of the invention may be a computer program product on a computer-usable storage medium having computer readable program code on the medium. Any suitable computer-readable medium may be utilized including, but not limited to, static and dynamic storage devices, hard disks, optical storage devices, and magnetic storage devices.

Certain embodiments of the invention are described herein with reference to flowchart illustrations of methods, systems, and computer program products. It will be understood that blocks of the illustrations, and combinations of blocks in the illustrations, can be implemented by computer-executable instructions. These computer-executable instructions may be provided to one or more processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus (or a combination of devices and circuits) to produce a machine, such that the instructions, which execute via the processor, implement the functions specified in the block or blocks.

These computer-executable instructions may also be stored in computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory result in an article of manufacture including instructions which implement the function specified in the flowchart block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions specified in the flowchart block or blocks.

What have been described above are examples. It is, of course, not possible to describe every conceivable combination of components or methodologies, but one of ordinary skill in the art will recognize that many further combinations and permutations are possible. Accordingly, the disclosure is intended to embrace all such alterations, modifications, and variations that fall within the scope of this application, including the appended claims.

As used herein, the term "includes" means includes but not limited to, the term "including" means including but not limited to. The term "based on" means based at least in part on. Additionally, where the disclosure or claims recite "a," "an," "a first," or "another" element, or the equivalent thereof, it should be interpreted to include one or more than one such element, neither requiring nor excluding two or more such elements.

What is claimed is:

1. A non-transitory computer readable medium having instructions, the instructions comprising:

a preprocessing stage to analyze input channel data for a plurality of input channels to detect channels having an integrity that is considered one of bad or good, each of the plurality of input channels corresponding to a respective one of a plurality of nodes;

a first spatial similarity measurement function to compute a measure of similarity between the input channel data for each of the plurality of nodes and a set of neighboring nodes to identify a spatial correlated set of channels having an integrity that is considered one of bad or good;

an amplitude analyzer to determine a subset of channels meeting amplitude criteria;

a second spatial similarity measurement function to compute, for each channel in the subset of channels meeting the amplitude criteria, a measure of similarity between the input channel data for each node and a set of neighboring nodes to identify an amplitude correlated set of channels having an integrity that is considered one of bad or good; and

a combiner to store output data representing the integrity of the plurality of input channels based on the integrity of the channels detected by the preprocessing stage, the spatial correlated set of channels and the amplitude correlated set of channels.

2. The medium of claim **1**, wherein the amplitude analyzer is further programmed to compare an amplitude value for each node relative the amplitude values for at least a substantial portion of the other nodes to determine temporary bad channels, which defines the subset of channels meeting the amplitude criteria.

3. The medium of claim **2**, wherein the second spatial similarity measurement function comprises a correlation calculator programmed to compute a cross correlation between the input channel data for each node, corresponding to the temporary bad channels, and the set of neighboring nodes.

4. The medium of claim **2**, further comprising an amplitude calculator to compute the amplitude values for each of the plurality of nodes based on the input channel data for each respective node.

5. The medium of claim **4**, wherein the second spatial similarity measurement function comprises a correlation calculator programmed to compute a correlation coefficient value between the computed amplitude value of each of the temporary bad channels and its local neighboring nodes, the amplitude correlated set of channels being determined based on a comparison of the correlation coefficient value computed for each node relative to a threshold value.

6. The medium of claim **5**, wherein the threshold value is one of programmable in response to a user input or a predetermined default value.

7. The medium of claim **1**, wherein the first spatial similarity measurement function comprises a correlation calculator programmed to compute correlation coefficient values from a cross correlation computed between each of the plurality of nodes and its local neighboring nodes, the spatial correlated set of channels being determined based on a comparison of the correlation coefficient value for each node relative to a threshold value.

8. The medium of claim **7**, wherein the threshold value is one of programmable in response to a user input or a predetermined default value.

9. The medium of claim **1**, further comprising a node distance analyzer to compute distance between nodes, each set of neighboring nodes being determined based on the distance between nodes.

10. The medium of claim **9**, wherein node distance is computed based on locations of nodes determined from geometry data that represents locations for the plurality of nodes.

11. The medium of claim **10**, wherein the geometry data is computed from imaging data for a plurality of sensors corresponding to the nodes.

12. The medium of claim **11**, further comprising a de-trend filter applied to the input data to provide de-trended input data, each of the first and second spatial correlation functions being performed on the de-trended input data.

13. The medium of claim **1**, wherein the preprocessing stage further comprises a saturated channel detector programmed to identify a disconnected condition of a sensor based on the input data prior to de-trending, the output data including channels identified by the saturated channel detector.

14. The medium of claim **1**, wherein the preprocessing stage further comprises a low amplitude detector programmed to identify each channel having an amplitude value that resides below a low amplitude threshold, the output data including channels identified by the low amplitude detector.

15. The medium of claim **1**, wherein the preprocessing stage further comprises a high amplitude detector programmed to identify each channel having an amplitude value that resides above a high amplitude threshold, the output data including channels identified by the high amplitude detector.

16. The medium of claim **1**, further comprising:

a resolution calculator to compute coefficients of a transformation matrix for at least a substantially portion of plurality of input channels based on the data representing the integrity of plurality of input channels; and

an evaluator to identify a low resolution spatial region based on an evaluation of the coefficients of the transformation matrix.

17. The medium of claim **16**, further comprising generating a graphical map depicting the low resolution spatial region.

18. The medium of claim **1**, further comprising a mapping system programmed to generate a reconstructed set of signals on an envelope based on input channel data and the output data, such that an interpolated value is used for each bad channel.

19. One or more non-transitory computer readable media that, when executed by one or more processors, perform a method comprising:

determining an amplitude for each of a plurality of input channels, corresponding to respective nodes;

computing a measure of similarity between the input channel of each node and the input channel of its neighboring nodes;

comparing the amplitude for each node relative to other nodes to determine temporary bad channels;

for each of the temporary bad channels, computing a measure of similarity between the input channel of each node and the input channel of its neighboring nodes;

identifying channel integrity for each of the plurality of input channels based on the computed measures of similarity; and

storing data associated with the identified channel integrity for each of the plurality of input channels in a memory.

20. The non-transitory computer readable media of claim **19**, further comprising determining a disconnected condition of a sensor for a given input channel to identify at least one bad channel.

21. The non-transitory computer readable media of claim **19**, further comprising comparing the amplitude of each input channel relative to a low amplitude threshold to identify at least one bad channel.

22. The non-transitory computer readable media of claim **19**, further comprising comparing the amplitude of each input channel relative to a high amplitude threshold to identify at least one bad channel.

23. The non-transitory computer readable media of claim **19**, wherein the measure of similarity computed for each of the temporary bad channels further comprises:

computing a correlation coefficient value between the computed amplitude value of each of the temporary bad channels and its neighboring nodes; and

comparing the correlation coefficient value computed for each node relative to a threshold value.

24. The non-transitory computer readable media of claim **23**, wherein the threshold value is a first threshold value and wherein the measure of similarity computed for each of the input channels further comprises:

computing a correlation coefficient value between the computed amplitude value of each of the temporary bad channels and its neighboring nodes; and

comparing the correlation coefficient value computed for each node relative to a second threshold value.

25. The non-transitory computer readable media of claim **24**, wherein the first threshold value is greater than the second threshold value such that the measure of similarity computed for each of the temporary bad channels is more strict.

26. The non-transitory computer readable media of claim **19**, further comprising computing a distance between nodes, the neighboring nodes for each respective node being determined based on the computed distance.

27. The non-transitory computer readable media of claim **26**, wherein node distance is computed based on locations of nodes determined from geometry data that represents locations for the plurality of nodes.

28. The non-transitory computer readable media of claim **19**, further comprising:

computing a resolution of reconstructed signals based on the plurality of input channels; and

comparing the computed resolution relative to a threshold to identify at least one region of low resolution resulting from the identified bad channels.

29. One or more non-transitory computer readable media that, when executed by one or more processors, perform a method comprising:

determining an amplitude for each of a plurality of input channels, corresponding to respective nodes;

computing a measure of similarity between the input channel of each node and the input channel of its neighboring nodes;

comparing the amplitude for each node relative to other nodes to determine temporary bad channels;

for each of the temporary bad channels, computing a measure of similarity between the input channel of each node and the input channel of its neighboring nodes;

identifying channel integrity for each of the plurality of input channels based on the computed measures of similarity; and

computing a resolution of reconstructed signals based on the plurality of input channels;

identifying at least one region of low resolution resulting based on the computed resolution; and

generating a display of a graphical map representing the region of low resolution.

30. The non-transitory computer readable media of claim **19**, further comprising generating a reconstructed set of signals using an inverse method based on the plurality of input channels, in which the identified bad channels are excluded from the generating and an interpolated channel value is used in place each identified bad channel.

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